NOTES ON THE DISINTEGRATION OF GRANITE IN EGYPT[1]

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INTRODUCTION

The disintegration of the granite in Egypt has been treated in a general way by Walther in his discussions of disintegration in desert regions. It has been commented on by Ball and others. The disintegration of the New York obelisk, composed of the Syene red granite, has been reported upon by Julien. The following notes were made by the writer in a recent trip to Egypt in which especial attention was paid to the disintegration manifested by the granite in the ancient quarries and ledges of the Aswan district and in the temples and monuments of Upper and Lower Egypt.

THREE PERIODS OF DISINTEGRATION IN THE ASWAN DISTRICT

The disintegration in the Aswan district seems to belong to two periods other than the present. The products of what seem to be the earliest period of disintegration are found at the contact of

[1] This paper is the result of work done as Sheldon Traveling Fellow, Harvard University.

coarse Syene red granite with the base of the overlying Nubian sandstone (Cretaceous) (Fig. 1). They form a zone of what Ball designates as "broken-down granite, a kaolinic mass with quartz grains." The zone is 1 to 1½ m. in thickness, has a relatively sharp even contact with the overlying sandstone and conglomerate, but below grades through less and less disintegrated granite into comparatively unaltered rock. The upper part of the zone is composed of material that has suffered slight rearrangement, but the middle and lower portions consist of the untransported débris of disintegration. The feldspar of the upper portion is almost completely kaolinized. In the middle portion, the kaolinization

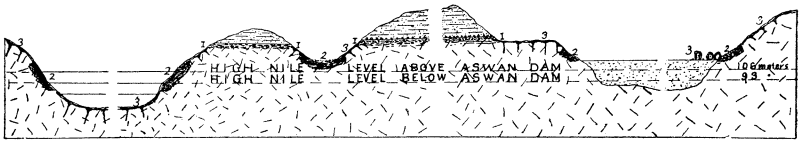

FIG. 1.—Diagrammatic section across the region of the Aswan Cataract. 1, Disintegrated and decomposed zone at the base of the Nubian Sandstone. 2, The massive granular disintegration. 3, Disintegration of the present.

is much less and in the lower portion it is not megascopically noticeable. Although the disintegration was seemingly not of the exfoliation type,[1] it nevertheless took place roughly parallel to the very level upper surface of the granite. The surface is so level as to suggest a peneplain surface. The disintegration would seem to have taken place contemporaneously with or immediately preceding the deposition of the Nubian sandstone, and the kaolinization may

[1] According to the present use of the term, it is possible to distinguish several types of disintegration. The term is applied in some cases to the breaking up of a rock-mass into blocks and in other cases to the breaking up of a rock-mass through the loss of cohesion between the constituent grains. The former process may be termed "block-disintegration" and the latter, "granular-disintegration." Allied to the block disintegration is what may be termed the "exfoliation" type of disintegration in which thin plates of rock rift off parallel to the surface of a ledge or block. The process seems to involve considerable loss of cohesion between the grains and readily goes over into granular disintegration. The term disintegration is also used in a loose sense to denote the chemical breaking up of the rock-mass. But as Merrill advises, it would seem better exclusively to use for that process the term "decomposition" and to reserve the term "disintegration" for the process of mechanical breaking up.

have taken place under the estuarine or marine conditions then prevailing or at some later time under the action of ground-water. The disintegration and decomposition penetrate cracks to the depths of 10 to 20 ft. and in one or two places may be seen to have taken place before the disintegration next to be mentioned.

The effects of the second period of disintegration are manifested in a tendency toward deep, granular disintegration massively affecting the coarse Syene red granite at a level which is approximately that of the Aswan Reservoir when full. This disintegration is best seen on the island of El Hesa, in some recently excavated graves at the site of the former village of Garba. The graves are cut back into hill slopes of various inclination and have a horizontal depth of about 3 meters on the average and a height of about $1\frac{1}{4}$ m. The roof at the back commonly has a thickness of 1 to 2 m. The greatest distance to which a grave was seen to extend horizontally backward from the surface of the hill slope was 4 m. The height of the grave was about $1\frac{1}{2}$ m. and the roof at the back was slightly over 2 m. in thickness. The graves are cut entirely in the disintegrated, or rather, partially disintegrated, granite and in no case were they seen to penetrate unaffected rock. The disintegration has therefore penetrated to a depth of at least 3 to 4 meters from the surface. The disintegration is of the granular type and, although affecting the rock uniformly, is not quite complete; blocks of the granite may be obtained which to the eye seem entirely sound but which crumble readily under the hammer. In the shallow sections that are afforded there is not any appreciable decrease of intensity of the disintegration with depth. The disintegration has been accompanied by slight but megascopically noticeable kaolinization and in its products resembles closely the partial granular disintegration which is found at a depth of about 4 m. in the Morvan and Plateau Central regions of Central France. This tendency toward massive granular disintegration is manifested also at several points along the old Nile Valley about 1 km. north-northeast of Shellal, at several points along the river trail from Shellal to the Aswan Dam, at several points immediately north of the village of Kuror along the river trail to Aswan, and about one-half mile northeast of Kuror in a small pass on the trail

to Aswan. The disintegration in each of the cases is approximately at the elevation of that on El Hesa. It is a distinctly noticeable fact that in many of these cases, as for instance in the case of the grave on El Hesa cut 4 m. back into a northerly facing 40° slope lying at the foot of a cliff about 25 m. high, the disintegration has penetrated to a depth of at least 3 to 4 m. in spite of the fact that direct isolation is received only during the summer and then only at a low angle.

Disintegration taking place under the present conditions is abundantly shown by most of the exposed ledges and loose blocks of the region and is manifested in three ways: (1) Surfaces which have been exposed for a relatively short while show a slight roughening. Individual grains and fragments of feldspar and of quartz become loosened and are removed. (2) Surfaces which have been exposed for a longer time show in addition exfoliation of thin superficial layers commonly of about two-thirds of a centimeter in thickness. Cross-sections afforded by broken blocks show that megascopically noticeable incipient exfoliation has penetrated to a depth of 10 to 15 cm. from the surface. (3) Disintegration takes place also by the spalling and splitting of large blocks and fragments, but the amount of disintegration taking place in this manner in the Aswan region is not very great. Of these three methods of disintegration that by exfoliation is by far the more important. In the excavation for the dam and navigation canal, concentric disintegration and decomposition were found to have penetrated to a depth of several meters below the high Nile level and are probably to be considered as going on at the present.

The chief granite of the Aswan region is the famous Syene red granite, a coarse red porphyritic granite composed chiefly of large phenocrysts of orthoclase. Where the joints are comparatively far apart, its outcrops under the effect of the concentric exfoliation of the joint blocks resemble huge piles of bowlders. Where the jointing is more pronounced and the joint blocks of much smaller size, the concentric exfoliation is much less in evidence and the outcrops are composed of, and surrounded by, detrital masses of angular and subangular blocks and in appearance are very similar

to the outcrop and surrounding detrital slopes of similar types of rocks in New England.

The fine-grained granite of the region, somewhat similar in composition to the coarse red granite, although with a lower content of colored silicates, is not so severely affected by the disintegration. Exfoliation takes place very slowly, and although the edges and corners of exposed blocks have in most cases been rounded, the general form of the blocks is angular. The outcrops in general aspect are not unlike these of the more jointed phases of the coarse red granite. The fine-grained granite is, however, itself much jointed. It was not seen massively disintegrated and small dikes cutting the massively disintegrated coarse granite showed merely slight exfoliation of the edges and corners of the joint blocks into which the dike is broken. Flaking and the loosening of single grains on exposed surfaces do not seem severely to affect the fine-grained granite.

THE RATE OF THE DISINTEGRATION OF THE GRANITE

The rate of disintegration of exposed surfaces of granite at Aswan is not as rapid as at first might seem. Many of the numerous hieroglyphic inscriptions of this region show noticeable disintegration and on this account relatively rapid rates of disintegration have been postulated. These inscriptions almost without exception are carved on bowlders of exfoliation, and in but few cases was there seemingly much effort on the part of the ancient Egyptians to remove more than the most readily detachable plates of exfoliation. The greater number of the inscriptions therefore were carved on surfaces that were already partially disintegrated. In the few cases in which the writer was able to satisfy himself that the inscriptions had been cut in surfaces dressed back into fresh rock, there was no disintegration noticeable and the inscriptions were entirely fresh and sharp. Such inscriptions can be seen on one of the two natural obelisks on the island of El Hesa. The inscriptions date from the reigns of Mentuhotep I, about 2100 B.C.; Thutmoses IV, 1420–1411 B.C.; Amenhotep III, 1411–1395 B.C.; and Psammeticus II, 588–583 B.C. The inscriptions show no noticeable disintegration, and tapping with the finger or hammer

does not reveal the presence of incipient exfoliation or flaking. The exposure is southerly and therefore one that affords the maximum exposure to insolation. These rocks, as can be seen from Fig. 2, rise directly out of the Nile and there would seem to have been no chance of their having been buried and protected by accumulations of sand or débris. Other examples of inscriptions carved in fresh surfaces and not showing disintegration are those

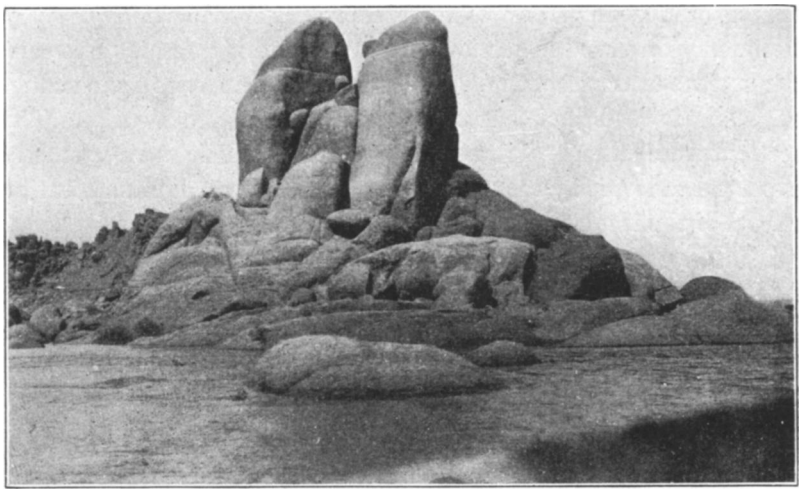

FIG. 2.—The Island of Konosso. View taken looking north-northeast. The hieroglyphics mentioned are on the south face of the right hand of the two natural monoliths.

along the trail from Aswan to Shellal numbered by Weigall 323, 326, 334, 343, and 350 and dating from the eleventh, twelfth, and thirteenth dynasties; an obelisk and a statue lying unfinished in the ancient quarries and referred by Wiegall to the reign of Amenhotep III, 1411–1375 B.C., and numerous discarded quarry blocks in the ancient quarries and along the ancient quarry roads, dating probably from not later than the last century B.C. These blocks in many cases consist of a half, a quarter, or an eighth of a bowlder of exfoliation and in most cases it is readily possible to determine which were the originally fresh and which were the originally exfoliating surfaces. The surfaces which were originally fresh are still

fresh and show merely an infinitesimally thin film of tarnish and alteration. Tapping revealed no incipient exfoliation. In microscopic thin sections taken at right angles to the surface of a block, the orthoclase is seen to be comparatively fresh; the oligoclase is much clouded by decomposition products, but the alteration is not sufficient to obscure the specific determination of the feldspar. The ferro-magnesian minerals show slight decomposition and in one of the sections there is considerable limonitic staining. The degree of decomposition is no greater than that which is very commonly observed in sections of granite and is no greater toward the surface than deeper in. There is no tendency, as far as could be seen, toward incipient rifting parallel to the surface. The sections were taken at right angles to surfaces which had a southerly exposure and which were therefore exposed to the maximum heating effects of the insolation.

Farther north in Egypt the rate of disintegration is more rapid. At Luxor, Thebes, Gizeh, and in the museum at Cairo, the granite (chiefly the coarse Syene granite) of statues, of obelisks, of portions of the temples, and of the facing of the pyramids, shows in the greater number of cases noticeable disintegration. That manifested by the statues is manifested chiefly as exfoliation of a thin film, 0.5–0.7 cm. in thickness, from the pedestal, feet, and lower portion of the legs. Above the knees, the original high polish is commonly still intact, and tapping does not reveal incipient exfoliation or flaking. Examples of this type of disintegration can be seen on many, but not all, of the statues of Rameses II in the Forecourt of the Temple of Luxor and by the statue of Rameses II at the north entrance, by the colossal statue of Rameses II at the entrance to the great Hypostyle Hall, Karnak (Fig. 3), and by the medium-sized statue in the temple of Ptah, and by about half the statues of the coarse red Syene granite and also those of dark medium-grained rock possibly diorite in the museum at Cairo. The statue in the Temple of Ptah is situated in a small dark sanctuary and is not directly exposed to insolation. The other statues at Luxor and Karnak are less well protected, but nevertheless are only very poorly exposed to the temperature changes consequent upon solar heating. In the Great Temple of Karnak,

disintegration manifests itself as the spalling of the corners of the uprights; as the exfoliation to the depth of about 1 cm. of the walls in the Granite Sanctuary, erected in 313 B.C. by Phillip Arrhidaeus; and as spalling and exfoliation of the lower 6 to 8 ft. of the fluted columns in front of the Sanctuary, and also of the obelisk of Queen Hatshepsut, 1591–1447 B.C. The obelisk of Thotmes I, now lying in pieces on the ground, shows scattered, patchy flaking and under tapping much incipient exfoliation is revealed. At the Temple of

FIG. 3.—Statue of Rameses II. Entrance to the Great Hypostyle Hall, Karnak, showing in a characteristic manner the exfoliation of the pedestal, feet, and lower legs.

Medinet Habu, Thebes, disintegration is shown by the granite pillars of the doorway both on the sides which are exposed to the sun and on those which are not. In the Serapeum at Sakkara, on the other hand, the surfaces of the huge sarcophagi, which are hewn out of the coarse Syene red granite, still retain the high perfection of their original polish and show not the faintest trace of incipient disintegration or exfoliation. The sarcophagi, however, are in dry underground chambers whose temperature, according to Baedecker, remains very constantly at about 80° F.

At Gizeh, the granite blocks which formed a part of the facing of the second and third pyramids show for the most part on their

exposed surfaces a very marked exfoliation to the depth of 0.5 to 0.8 cm. Minor exfoliation, in addition, is found along the joints between the blocks. Exposed surfaces not exfoliating commonly show marked granular flaking. The orientation of the surface, with north, east, south, or west exposure, does not seem appreciably to affect the intensity of the disintegration and exfoliation. Disintegration and exfoliation are shown also by the granite facing that extends for 30 ft. down the shaft on the north side of the second pyramid, by the granite pavement of the temple at the east base of the second pyramid, and by the granite blocks immediately to the north of the east entrance to the temple. A striking feature

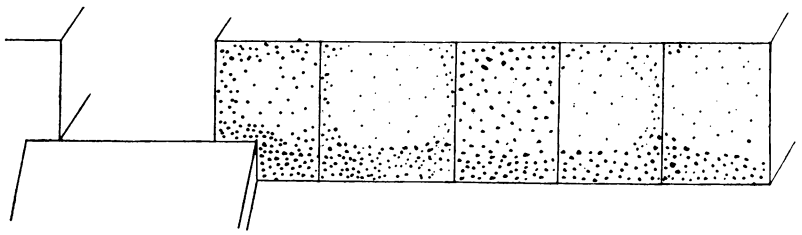

FIG. 4.—Diagrammatic sketch showing the greater degree of disintegration below the old soil line than above. East entrance to the temple of the second pyramid, Gizeh.

in this latter case, as can be seen from the accompanying sketch (Fig. 4), is that the disintegration is distinctly stronger below what seems to have been an old soil line than above it. A similar case was noted at one of the pyramids at Sakkara. The débris resulting from the disintegration and exfoliation in all these shows slight but megascopically noticeable decomposition. The degree of the alteration of the colored silicates is greater than that of the feldspars, and that of the plagioclase is greater than that of the orthoclase.

The pyramids of Gizeh date from the Fourth Dynasty, about 2850–2700 B.C., the statues of Rameses II at Karnak and Luxor date from the Nineteenth Dynasty, 1292–1225 B.C., and the Granite Sanctuary, Karnak, dates from the reign of Phillip Arrhidaeus, 318 B.C. The average rate of disintegration and exfoliation would therefore seem to be about 1 cm. to 0.5 cm. in five thousand years.

The maximum rate, shown by the Granite Sanctuary, would seem to be about 1 cm. in two thousand years, and the minimum rate would seem to be so low that the effects are not apparent in three thousand years. In addition to this variation in the rate of disintegration apparently corresponding to a variation in the conditions to which the granite is exposed, there is apparently also a variation depending upon the orientation of the disintegrating surface in reference to certain directions within the rock, possibly the rift and the grain, or possibly a faint schistosity which is almost universally present in the Syene granite.

THE CAUSES OF THE DISINTEGRATION

The conventional explanation of disintegration in a region of desert climate like that of Egypt is that the disintegration results from the racking to pieces of the rock through the contraction and expansion consequent in the high-temperature ranges. In the case of Egypt, there would, however, seem to be serious objections to this explanation, although some disintegration undoubtedly does take place in that manner. The first objection is that, although the temperature range is of the same magnitude at both Aswan and at the pyramids of Gizeh, the rate of exfoliation is very much less at the former place than at the latter, and furthermore, that, although the statues in the temples are exposed in many cases only to very low temperature ranges, the rate of exfoliation in many of these cases is of the same magnitude as that at the pyramids of Gizeh. The second objection is that the massive granular disintegration of the Aswan region penetrates to a greater depth than appreciable temperature changes can be expected to extend. The depth of the zone of warming at midday in desert regions is given by Walther as the result of many observations as only about 19 cm. The annual temperature variation is said by Sir William Thompson to be reduced at a depth of 8 m. (25 ft.) to one-twentieth of its superficial amount. The mean annual temperature range in Egypt is less than 20° C and, at the depths to which disintegration can be seen to have penetrated at Aswan, 3 to 4 meters, must be reduced to amounts which are essentially negligible, especially since the period of the range is so long. The mean monthly range

is only 24° C. and at those depths must be even more seriously reduced in amount. The diurnal temperature range, furthermore, should be entirely absent at those depths, especially on slopes such as those in which many of the graves on El Hesa are cut, where direct insolation is received only during the summer and then at a low angle. Granite itself has a low coefficient of conductivity and that of dry granitic sand must be much lower; it would therefore not seem surprising that a blanket of several feet of disintegrated granite is found to be an effective insulating agent for the fresh rock beneath.

At Aswan and at the pyramids of Gizeh, the only factor by which the conditions of exposure of the exfoliating rock differ is in the humidity. At Aswan there is no rainfall, there is only a light dewfall at night, and the relative humidity at 8:00–9:00 A.M. varies from 28 to 58, average 39; while at the pyramids of Gizeh there are several light showers each year, there is a moderately heavy dewfall at night, and the relative humidity at 8:00–9:00 A.M. runs from 64 to 87, average 72.

In the case of the exfoliating statues, their sheltered positions in the temples and the connection between the exfoliation and the lower portions of the statues would seem to indicate that the cause of the exfoliation lay not so much in the temperature changes as in some factor connected with the ground, as for instance, in the ground-water or moisture, and it is to such a cause that the exfoliation is ascribed by G. Daressy of the Department of Antiquities, Egypt, who says: "Les granites exposés continuellment à l'eau ou au soleil se conservent bien, mais où ils se degradent, c'est lorsqu'ils ont été enfouis dans un sol humide. La formation de sels nitrate et autre fait alors decomposer le granite, sûrtout lorsque le terrain est alternatement sec et humide." The expansion consequent upon the kaolinization of the feldspar is emphasized by Merrill as the cause of the disintegration of the granite near Washington, D.C. Although kaolinization is megascopically very noticeable in these cases, it would scarcely seem to be of sufficient amount alone to account for the observed disintegration and exfoliation.

The massive granular disintegration of the Aswan region possibly also may be attributed directly or indirectly to the effect of moisture. The disintegration is found at and for some few meters below the level at which the Nile must have flowed when in the old Nile Valley between Aswan and Shellal. At that time the granite at the level of this disintegration must have been alternately above and below the ground-water level, as the Nile rose and fell, and must consequently have been alternately wet and dry. At the present level of the Nile, the granite was found in the excavations for the navigation canal and for the dam foundations to be almost completely disintegrated and decomposed to a depth of several meters below the level of the high Nile. Decomposition in this case has, however, rather predominated over simple disintegration.

These observations in the light which they throw on the cause of the disintegration of granite are in agreement with similar observations which the writer made in the Odenwald, in the Vosges Mountains, in the Norvan and Auvergne districts of France, and in the eastern United States. In the many places in which the disintegration has reached the depth of 20, 30, or even 40 ft., it seems impossible to believe that the temperature changes are of sufficient amount to be of any appreciable effect. Diurnal, weekly, and monthly temperature changes must be completely eliminated at those depths, and according to Sir William Thompson the annual temperature range is reduced at a depth of 25 ft. to one-twentieth of its superficial amount. The disintegration in these places is accompanied in many cases by very much more and in other cases by only slightly more decomposition than is the disintegration in Egypt.